Deep Underground Detector Experiments

R(μ/e) = (Measured Ratio μ/e) / (Expected Ratio μ/e)

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
	[65] BECKER-SZ...	92B	IMB	Water Chernekov
$0.60^{+0.07}_{-0.06}\pm0.05$	[66] HIRATA	92	KAM2	Water Cerenkov
	[67] BERGER	90B	FREJ	Calorimeter

[65] BECKER-SZENDY 92B reports the fraction of nonshowering events (mostly muons from atomospheric neutrinos) as $0.36 \pm 0.02 \pm 0.02$, as compared with expected fraction $0.51 \pm 0.01 \pm 0.05$. After cutting the energy range to the KAM2 limits, BEIER 92 finds $R(\mu/e)$ very close to the KAM2 value.

[66] HIRATA 92 uses this ratio because both experimental and theoretical uncertainties in ν_μ and ν_e flux cancel. Part of data set is same as in HIRATA 88 (below), where the equivalent ratio was $0.56^{+0.09}_{-0.08}$.

[67] BERGER 90B reports $e/\mu = 0.53$–0.57 ± 0.09 (data) and 0.56–0.61 $\pm$ 0.08 (Monte Carlo), where the range is from different analysis methods. There is thus no significant departure from expectation. See also BEIER 92.

R(ν_μ) = (Measured Flux of ν_μ) / (Expected Flux of ν_μ)

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
	[68] CASPER	91	IMB	Water Cherenkov
	[69] AGLIETTA	89	NUSX	
0.59 ± 0.07	[70] HIRATA	88	KAM2	Water Chernekov
0.95 ± 0.22	[71] BOLIEV	81		Baksan
0.62 ± 0.17	CROUCH	78		Case Western/UCI

[68] CASPER 91 correlates showering/nonshowering signature of single-ring events with parent atmospheric-neutrino flavor. They find nonshowering ($\approx \nu_\mu$ induced) fraction is $0.41 \pm 0.03 \pm 0.02$, as compared with expected 0.51 ± 0.05 (syst).

[69] AGLIETTA 89 finds no evidence for any anomaly in the neutrino flux. They define ρ = (measured number of ν_e's)/(measured number of ν_μ's). They report $\rho(\text{measured})=\rho(\text{expected}) = 0.96^{+0.32}_{-0.28}$.

[70] HIRATA 88 error is statistical.

[71] From this data BOLIEV 81 obtain the limit $\Delta(m^2) \leq 6 \times 10^{-3}$ eV^2 for maximal mixing, $\nu_\mu \not\to \nu_\mu$ type oscillation.

$\sin^2(2\theta)$ for Given $\Delta(m^2)$ ($\nu_e \leftrightarrow \nu_\mu$)

For a review see BAHCALL 89.

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>0.33	90	[72] HIRATA	92	KAM2	$\Delta(m^2) > 0.004$ eV^2
<0.47	90	[73] BERGER	90B	FREJ	$\Delta(m^2) > 1$ eV^2
<0.14	90	LOSECCO	87	IMB	$\Delta(m^2)= 0.00011$ eV^2

[72] HIRATA 92 states that the allowed region for $\nu_e \leftrightarrow \nu_\mu$ conflicts with the constraints from the solar neutrino data (HIRATA 90B).

[73] BERGER 90B uses the Frejus detector to search for oscillations of atmospheric neutrinos. Bounds are for both neutrino and antinuetrino oscillations.

$\Delta(m^2)$ for $\sin^2(2\theta) = 1$ ($\nu_e \leftrightarrow \nu_\mu$)

VALUE (10^{-5} eV^2)	CL%	DOCUMENT ID		TECN
• • • We do not use the following data for averages, fits, limits, etc. • • •				
<150	90	[74] BERGER	90B	FREJ

[74] BERGER 90B uses the Frejus detector to search for oscillations of atmospheric neutrinos. Bounds are for both neutrino and antinuetrino oscillations.

$\sin^2(2\theta)$ for Given $\Delta(m^2)$ ($\nu_\mu \leftrightarrow \nu_\tau$)

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>0.5	90	[75] BECKER-SZ...	92	IMB	$\Delta(m^2)$= 1–2 $\times 10^{-4}$ eV^2
>0.42	90	HIRATA	92	KAM2	$\Delta(m^2) > 0.001$ eV^2
<0.6	90	[76] BERGER	90B	FREJ	$\Delta(m^2) > 1$ eV^2

[75] BECKER-SZENDY 92 uses upward-going muons to search for atomospheric ν_μ oscillations. The fraction of muons which stop in the detector is used to search for deviations in the expected spectrum. No evidence for oscillations is found.

[76] BERGER 90B uses the Frejus detector to search for oscillations of atmospheric neutrinos. Bounds are for both neutrino and antinuetrino oscillations.

$\Delta(m^2)$ for $\sin^2(2\theta) = 1$ ($\nu_\mu \leftrightarrow \nu_\tau$)

VALUE (10^{-5} eV^2)	CL%	DOCUMENT ID		TECN
• • • We do not use the following data for averages, fits, limits, etc. • • •				
<350	90	[77] BERGER	90B	FREJ

[77] BERGER 90B uses the Frejus detector to search for oscillations of atmospheric neutrinos. Bounds are for both neutrino and antinuetrino oscillations.

$\Delta(m^2)$ for $\sin^2(2\theta) = 1$ ($\nu_\mu \to \nu_s$)

ν_s means ν_τ or any sterile (noninteracting) ν.

VALUE (10^{-5} eV^2)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<3000 (or <550)	90	[78] OYAMA	89		Kamiokande II
< 4.2 or $> 54.$	90	BIONTA	88	IMB	Flux has ν_μ, $\overline{\nu}_\mu$, ν_e, and $\overline{\nu}_e$

[78] OYAMA 89 gives a range of limits, depending on assumptions in their analysis. They argue that the region $\Delta(m^2)$ = (100–1000) $\times 10^{-5}$ eV^2 is not ruled out by any data for large mixing.

Reactor $\overline{\nu}$ Experiments

Events (Observed/Expected) from Reactor $\overline{\nu}_e$ Experiments

VALUE	DOCUMENT ID		COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •			
$1.05\ \pm0.02\ \pm0.05$	VUILLEUMIER	82	$\overline{\nu}_e p \to e^+ n$
$0.955\pm0.035\pm0.110$	[79] KWON	81	$\overline{\nu}_e p \to e^+ n$
$0.89\ \pm0.15$	[79] BOEHM	80	$\overline{\nu}_e p \to e^+ n$
$0.38\ \pm0.21$	[80,81] REINES	80	
$0.40\ \pm0.22$	[80,81] REINES	80	

[79] KWON 81 represents an analysis of a larger set of data from the same experiment as BOEHM 80.

[80] REINES 80 involves comparison of neutral- and charged-current reactions $\overline{\nu}_e d \to n p \overline{\nu}_e$ and $\overline{\nu}_e d \to n n e^+$ respectively. Combined analysis of reactor $\overline{\nu}_e$ experiments was performed by SILVERMAN 81.

[81] The two REINES 80 values correspond to the calculated $\overline{\nu}_e$ fluxes of AVIGNONE 80 and DAVIS 79 respectively.

– – – – $\overline{\nu}_e \not\to \overline{\nu}_e$ – – – –

$\Delta(m^2)$ for $\sin^2(2\theta) = 1$

VALUE (eV^2)	CL%	DOCUMENT ID		TECN	COMMENT
<0.0083	90	VIDYAKIN	90		$\overline{\nu}_e p \to e^+ n$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[82] KETOV	92		
<0.04	90	[83] AFONIN	88	CNTR	$\overline{\nu}_e p \to e^+ n$
<0.05	68	[84] AFONIN	87		$\overline{\nu}_e p \to e^+ n$
<0.014	68	[85] VIDYAKIN	87		$\overline{\nu}_e p \to e^+ n$
<0.05	68	[84] AFONIN	86		$\overline{\nu}_e p \to e^+ n$
<0.019	90	[86] ZACEK	86		$\overline{\nu}_e p \to e^+ n$
<0.07	90	AFONIN	85		$\overline{\nu}_e p \to e^+ n$
<0.02	90	[87] ZACEK	85		$\overline{\nu}_e p \to e^+ n$
<0.016	90	[88] GABATHULER	84		$\overline{\nu}_e p \to e^+ n$
<0.1	90	AFONIN	83		$\overline{\nu}_e p \to e^+ n$
<0.13		BELENKII	83		$\overline{\nu}_e p \to e^+ n$

[82] KETOV 92 is a limit from search for $\overline{\nu}_e$ oscillations using the reaction $\overline{\nu}_e p \to e^+ n$ with the $\overline{\nu}_e$ flux from the Rovno power reactor. They obtain the ratio $R = 0.976 \pm 0.02 \pm 0.015$ for the corrected flux ratios at 12 m and 18 m from the reactor core, and thus report no evidence for neutrino oscillations over distances of order 10 m. Virtually no experimental details are given.

[83] Several different methods of data analysis are used in AFONIN 88. We quote the most stringent limits.

[84] AFONIN 86 and AFONIN 87 also give limits on $\sin^2(2\theta)$ for intermediate values of $\Delta(m^2)$.

[85] VIDYAKIN 87 bound is for L = 32.8 and 92.3 m distance from two reactors.

[86] This bound is from data for L=37.9 m, 45.9 m, and 64.7 m distance from Gösgen reactor.

[87] See the comment for ZACEK 85 in the section on $\sin^2(2\theta)$ below.

[88] This bound comes from a combination of the VUILLEUMIER 82 data at distance 37.9 m from Gösgen reactor and new data at 45.9 m.

$\sin^2(2\theta)$ for "Large" $\Delta(m^2)$

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.14	68	[89] VIDYAKIN	87		$\overline{\nu}_e p \to e^+ n$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.2	90	[90] AFONIN	88	CNTR	$\overline{\nu}_e p \to e^+ n$
<0.21	68	AFONIN	87		$\overline{\nu}_e p \to e^+ n$
<0.21	90	[91] ZACEK	86		$\overline{\nu}_e p \to e^+ n$
<0.34	90	AFONIN	85		$\overline{\nu}_e p \to e^+ n$
<0.19	90	[92] ZACEK	85		$\overline{\nu}_e p \to e^+ n$
<0.16	90	[93] GABATHULER	84		$\overline{\nu}_e p \to e^+ n$
<0.4		[94] BELENKII	83		$\overline{\nu}_e p \to e^+ n$

[89] VIDYAKIN 87 bound is for L = 32.8 and 92.3 m distance from two reactors.

[90] Several different methods of data analysis are used in AFONIN 88. We quote the most stringent limits. Different upper limits on $\sin^2 2\theta$ apply at intermediate values of $\Delta(m^2)$.

[91] This bound is from data for L=37.9 m, 45.9 m, and 64.7 m distance from Gosgen reactor.

[92] ZACEK 85 (Gosgen reactor) gives two sets of bounds depending on what assumptions are used in the data analysis. The bounds in figure 3(a) of ZACEK 85 are progressively poorer for large $\Delta(m^2)$ whereas those of figure 3(b) approach a constant. We list the latter. Both sets of bounds use combination of data from 37.9, 45.9, and 64.7m distance from reactor. ZACEK 85 states "Our experiment excludes this area (the oscillation parameter region allowed by the Bugey data, CAVAIGNAC 84) almost completely, thus disproving the indications of neutrino oscillations of CAVAIGNAC 84 with a high degree of confidence."

[93] This bound comes from a combination of the VUILLEUMIER 82 data at distance 37.9m from Gosgen reactor and new data at 45.9m.

[94] This bound holds for $\Delta(m^2) > 4$ eV^2.